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# MOTORISATION—THE ELIMINATION OF BELT DRIVE.

*Paper presented to the Institution, Coventry Section, by G. W. Batchelor.*

THE application of electric motor drives to machines does not always mean complete elimination of belt drive at the present day, but motorisation does invariably mean elimination of line shaft drive. Belt drives have so long been used for transmitting rotation, for starting and stopping machines, reversing, converting, and selecting speeds that one cannot lightly speak of eliminating belt drive without being quite convinced that progress has made them obsolete for modern production as they, in turn, made hand machines obsolete.

A form of hand-operated belt drive has been used on primitive lathes for some thousands of years. The introduction of line shaft drive, however, marks the beginning of mechanically-driven machine tools as distinct from hand-operated machine tools such as Robert's planing machine. A belt pulley drive from line shafting would undoubtedly have been a relief to the man who had to operate the hand levers of this early and surprisingly well designed planing machine. When power in the shape of a steam engine took the place of manual labour, the only means of distributing this power was through the mechanical agency of line shafting and belts. If at that time there had been available some simple, compact, robust, reliable type of motor, such as the squirrel cage induction motor, it is extremely doubtful whether line shafting would have developed to any great extent.

## Line Shaft Drive.

When large electric motors began to replace various types of prime mover, engineers became more conscious of power consumption. The big idling power wasted by the line shafting, whether driving one or twenty machines, was much more clearly revealed, whilst the need for starting up line shafts half an hour or so before work commenced was called into question. Factories were sectionalised into group drives, thus reducing the risk of complete shutdown, and the logical sequence of this tendency has been further to reduce the risk to a minimum by making each machine

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tool an individually driven section of its own. If it is accepted that movement is the source of wealth and that without movement wealth cannot be created, it would follow that unnecessary movement is wasted wealth. Movement which is interposed between the driving motor and the working tool is wasted movement if it is merely transmitting a drive and not in some other way helping to render the operation more efficient.

The loss of power due to friction in line shaft drives is said to average 35% reaching, in some cases, as much as 50% of the total power required to drive the group. (Prof. Charnock, page 936). In one particularly bad case it was found that between 65% and 70% of the power developed by an engine was absorbed in the line shafting, bevel gears, etc. (Prof. Charnock, page 967).

The average loss mentioned above of 35% was based upon the use of journal bearings, and the reduced friction due to ball and roller bearings is reckoned to be between 3/4 and 3/8 of the losses in journal bearing shafting. This figure is very strikingly borne out by some tests made by Wadkin of Leicester a few years ago to determine the light running line shaft consumption. In this case the line shafting was of modern design split into five groups of about 20 h.p. each, the shafting being well designed, solidly supported and running in ball bearings. In making the tests certain bits of countershafting had to be omitted, and of course the line shafts were unloaded.

The following figures indicate consumption for the five different groups :—

| | | | | | | |
|---|---|---|---|---|---|---|
| 20 h.p. | 950. | p.m. | motor | 7,600 | units | per annum |
| 20 h.p. | 950 | ,, | ,, | 9,693 | ,, | ,, |
| 20 h.p. | 950 | ,, | ,, | 9,693 | ,, | ,, |
| 17½ h.p. | 1,440 | ,, | ,, | 4,145 | ,, | ,, |
| 20 h.p. | 940 | ,, | ,, | 8,636 | ,, | ,, |
| | | | | 40,000 | | |

Total working consumption for the year was 262,000 units.

Based on a forty-seven hour week the annual consumption in the line shaft alone was 40,000 units out of a total of 262,000 units. This, under very best conditions, indicates a loss of 15% with the the line shaft unloaded and without running the countershafting associated with a number of machines. The power required to bend the belt cannot be ignored and a lot depends upon such factors as diameter of pulley, thickness and width of belt, tightness of belt, etc., but it is interesting to note that a test on a 12 in. belt showed that it absorbed 1.5 h.p. irrespective of any bearing friction (Prof. Charnock, page 961).

An economical line shaft drive depends upon many factors, some of them difficult to control, quite apart from the weight of the shafting and pull of belts. Inaccurate methods of supporting and aligning must obviously be avoided, but the subsidence of foundations, bulging of walls, and deflection of columns and girders are factors which can all reduce efficiency.

The erection of new line shafting needs very careful planning and attention to the rigidity of the building structure to avoid bending stresses, loss of power and other troubles in the line shaft,

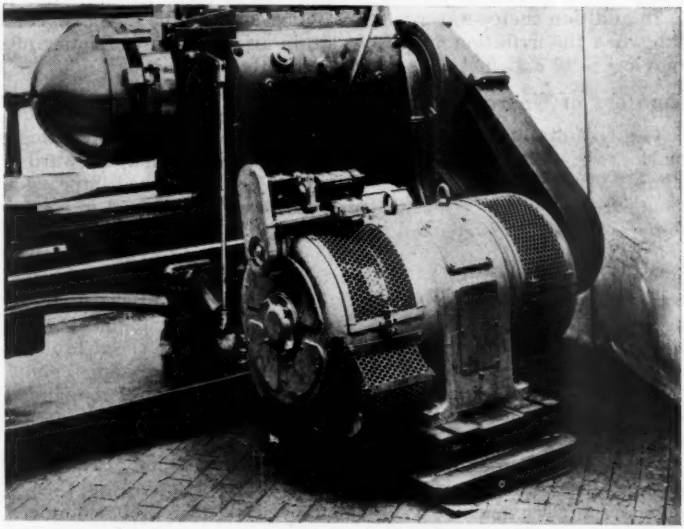

**Fig. 1.—Step-less speed variation for spherical turning on Ward capstan lathe by variable speed A.C. commutator motor.**

so that the cost of the building may well be increased. The longitudinal girders between bays are favourite supports for line shafting because this arrangement allows minimum interference with crane transport, and least obstruction to light. In wide bays, however, adherence to this arrangement may result in awkward production grouping of the machines and cross joists become necessary to support further countershafting in the middle of the shop. Alternatively, resort may be had to individually driven machine tools occupying the middle portion of the bay, and if suitably chosen, these are available for overtime, short time, or night shift working.

Machine shops operating under conditions of modern production

are often severely hampered by the existence of line shafting because shop planning re-arrangements and additions to plant are subject to irritating restrictions. It is becoming very widely recognised to-day that the removal of overhead line shafting is not only desirable but in some cases, a vital necessity and some of the main reasons are: Greater personal safety ; improved lighting ; reduced noise ; much greater mobility ; easier grouping ; lower maintenance cost ; saving in power, especially when all machines are not working as on overtime, night shifts, short time working, or particularly where setting up time is a fairly high factor.

In addition the operator is much more comfortable at his or her job when the irritation and nerve strain arising from proximity of moving belts and flickering shadows has been eliminated.

**Comfort of Operators.**

The comfort and convenience of the man or woman operating machines is rightly being studied very closely in the move towards elimination of hindrances to production. A very marked improvement in earning power and attention to work is observed in some shops which have been made attractive, clear, well lighted, and quieter by removal of overhead line shaft and belting. These advantages arise merely from the application of individual drives and do not fully take into account one of the most important features of electric motor drives, namely, the use of all the available possibilities of electric operation in changing speed, high speed, quick stopping, reversing, dealing flexibly with each load, avoiding completely the power and speed limitations of the belt, and of changing from one condition to another with the ease demanded in modern duty cycles. It is in this development in the design and applications of electric motors and control which is increasingly responsible for the very great improvement in machine tool design, and there are many modern machine tools which would be incredibly complicated without the use of electric motors with appropriate control gear to give required speed variation, starting, stopping and various auxiliary movements.

**Individual Drive.**

Even where motorised machines are belt driven, the belts are shorter, can be completely enclosed ensuring perfect safety, can be kept clean and more easily maintained, whilst the machine has the advantage of being independently driven unit permitting free access on all sides and unrestricted choice of situation.

Reliability is a question of the greatest importance and here it will be agreed that the individually driven machine tool is better. The small induction motor used for individual drive is just as reliable as the larger motor used for group drive and it is obvious that

breakdown of the larger motor is a much more serious matter than the breakdown of the small individual drive motor which, anyhow, can be much more easily and cheaply replaced.

The power factor and efficiency of a few large motors compared with that of a large number of small motors is often discussed, and it is true that a large motor running fully loaded has inherently better efficiency and power factor than a small motor running fully loaded. As against this, however, a motor individually driving a machine tool if correctly designed for the application can usually be operated at its most efficient point, whilst when the machine is

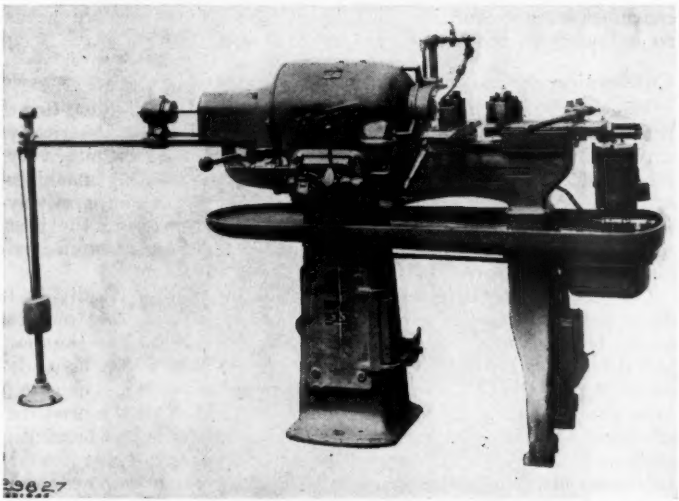

**Fig. 2.—Four-speed changepole motor unit built into headstock of Ward capstan showing changepole built-in controller and contactor gear in leg of lathe.**

not working the motor is completely shut down. These shut down periods include the time required for setting up. They represent pure saving and the factor can be a very important one depending upon the type of production in the shop. On the other hand, when group driven machines are not all working, the line shaft is still being turned round and the fewer machines operating the worse becomes the efficiency and the power factor of the group drive motor. This is a practical condition whose losses can very quickly offset the somewhat better full load performance of bigger motors.

**Power Factor Correction.**

Power factor correction must always be considered even if no bonus is offered by the power company, because loading of electric cables can be very seriously affected. Improvement of power factor may save re-wiring the machine shop by permitting increased loading of perhaps 25 or 30% depending upon the improvement effected. These possibilities exist whether the shop is run on the group system by a few large motors or individually by a large number of small motors. In the latter case, very great care should be taken to ensure that the motors installed are the correct rating for the duty. Machine tool maker's ratings have been known to err considerably on the high side, especially when estimated for machines intended for line shaft drive. This point, therefore, needs to be carefully checked when changing over.

**Conversion of Existing Machines.**

When a change is made from line shaft drive to individual drive replacement of the old machine tools by modern all-electrically driven tools might be considered desirable, yet conditions very rarely permit so drastic a replacement and the existing machines are more often fitted with individual motors using a comparatively short belt drive, and if this is done with knowledge of the best manner of applying motoss to each tool, the performance of even old machines can often be improved.

Conversion of existing machines from line shaft to individual drive presents various mechanical problems in mounting motors to the best advantage in conformity with the direction of the new belt drive, together with space economy. Provision has to be made for tensioning the belt, working in the best pulley ratios and deciding upon the right type of belt to use, all bearing in mind the need for efficiency and the avoidance of harmful stresses either in bearings, shaft or the machines structure. The motor and control gear should be chosen not only with a knowledge of the exact horsepower and speed required and the operation cycle, but also with a sound idea of what characteristics and type of electric motor and control gear can be obtained, suitable for connecting to the supply available.

Help in these matters is always willingly given by electrical manufacturers and the rightness of this selection will entirely govern the performance of the rejuvenated machine tool and determine whether the changeover gives only the advantages of the individual drive or whether, in addition, can be added some of the benefits of the real electric machine tool. On the one hand, from the point of view of production the machine tool remains as before, a belt driven tool, but on the other hand the performance of the machine tool itself may be improved by making use of available motor characteristics.

Some notes made of actual changeovers may be of interest.

A factory situated in the Midlands is engaged in the production of a very wide range of small parts. The shop contained about 150 machine tools of various designs such as capstan lathes, vertical and horizontal milling machines, sensitive drills, radical drills, vertical boring machines and a variety of other machines such as grinders, profilers etc.

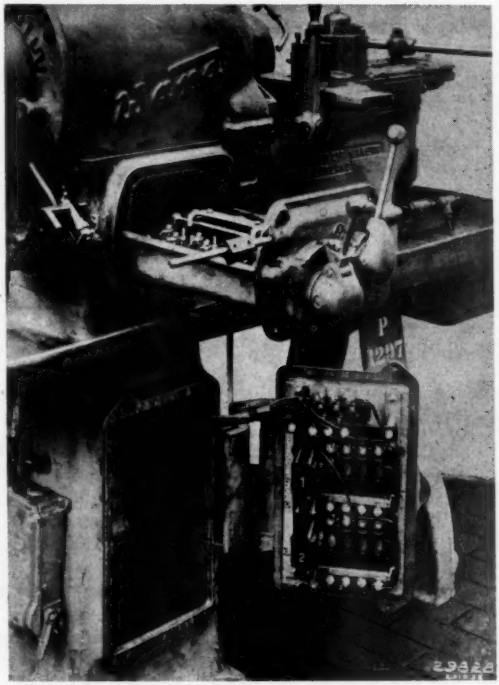

**Fig. 3.—Ward capstan lathe showing easy accessibility to built-in changepole selector switch and contactor gear.**

The shop contained 43 motors varying from 20 h.p. down to ½ h.p. with a total connected capacity of 265 h.p. About one third of these machines were already individually driving their tools. After the conversion to individual drive the shop contained about 190 motors including some additional machine tools, with a total connected horsepower of 340 h.p.

A battery of Ward capstan lathes originally had three step

pulleys with a total of six speeds, part of the speed change being made by manipulating foot levers underneath the lathes. These have now been supplied with 3 h.p. changepole motors, the lathe capacities being $1\frac{1}{4}$ in. and $1\frac{1}{2}$ in. diameter bars.

The motors were designed with four speeds operated by means of a changepole selector switch, the four motor speeds being 1,450, 960, 720, and 465 r.p.m., but the second speed, namely, 725 r.p.m., is permanently connected in reverse so that the changepole switch lever gives three forwards and one reverse speed.

The motors are mounted on a hinged base giving automatic belt tension driving to a countershaft and from there to the three step pulley on the lathe spindle. This gives a choice of nine speeds, three on each pulley. Each range of three speeds and reverse is obtained by simple movement of the changepole lever but change of range necessitates changing the belt on the cone. For any given job, however, the operator merely flicks the selector switch handle from one position to another.

The actual range of final speeds on the lathe spindle is as follows :—

Small diameter pulley : 180 r.p.m., 375 r.p.m., 560 r.p.m., 280 r.p.m. reverse.

Medium diameter pulley : 320 r.p.m., 670 r.p.m., 1,000 r.p.m., and 495 r.p.m. reverse.

Large diameter pulley : 560 r.p.m., 1,185 r.p.m., 1,780 r.p.m., and 865 r.p.m. reverse.

The reverse speed was chosen as being suitable for the work but any of the other speeds could have been used if preferred. Horsepower tests resulted in cutting down the original proposal of 4 h.p. to 3 h.p., which has been satisfactory. Under various conditions the horsepower demand ranges from 1.6 h.p. up to 4.3 h.p., and this latter figure is easily within the overload capacity of the 3 h.p. motor. It should be noted that the reduction saves waste in several directions as the smaller motor is cheaper, lighter, and works at its most efficient average point maintaining a high power factor, thereby saving current and avoiding overload of shop wiring. As the motors are being constantly started, stopped and reversed further saving follows from reduction in diameter of the motor rotor which thus uses less power in acceleration, deceleration and plug stopping. By plug stopping a saving of several seconds is made each time the motor is brought to rest.

Some 80 to 100 cycles of operations per hour are commonly performed on these lathes, so that a few seconds saved on each operation means a very big total gain in time. Further, when operating at this rate the change from the old clumsy foot operation of speed changing to the light finger-tip electric speed change,

both saves time and conserves personal energy to a valuable degree.

Motorisation of existing bar automatics uses two motors, one for the spindle and one for the drum. In this case the starters were so connected as to provide an interlock to cut out the risk of damage which might arise if the feed should be continued with the work spindle motor shut down.

Vertical milling machines and boring machines have been motorised in much the same way by using changepole motors

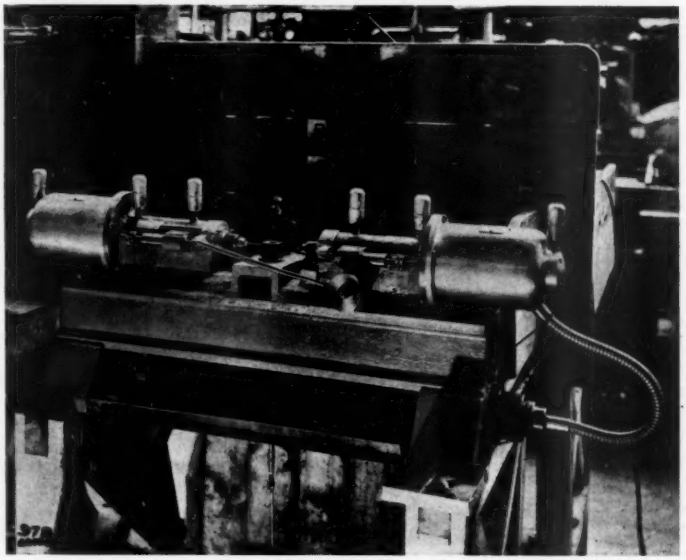

**Fig. 4.—8,700 r.p.m. high frequency sensitive drill with built-in motor unit operating from frequency changer. Drilling machine manufactured by Jos. Tucker for dolly drilling.**

instead of three step pulleys. Although in these cases changes in speed are less frequently needed, the elimination of belt changing in favour of selector switch lever operation is a distinct saving in time and effort and does make the machine more attractive to work. Radial drills were already motorised. Comparison of production after the conversion with that obtained before shows at a moderate estimate 10% increased output. Under the older conditions an appreciable amount of time was lost by operators leaving their machines for a few moments respite from time to

time during the day. Operation of the comparatively heavy belt striking gear, particularly by girls, caused fatigue and loss of energy which now is more willingly utilised on the increased output. Hindrances due to belt repairs have been reduced to a negligible amount and the operators in general are much keener and more interested in their job.

**Cost.**

The cost of converting small machine tools varies very greatly from approximately £35 in the case of a changepole equipment down to about £10 for simpler jobs. Obviously these figures can only give a very rough idea and depend entirely upon the tool and the equipment. It is commonly thought that individually driven machine tools cost more to run than group-driven machines, and the idea on paper is plausible, perhaps in some cases it may be true. I would say, however, that for most machine shops this belief can be a complete fallacy. Quite apart from an indisputedly large save in maintenance, belt repairs, lost time, and the consequent dislocation caused by shut-down of the group. A saving in power consumption is indicated by the readings taken in three widely different factories. In the factory described above the ratio of power consumption to output fell in the ratio of 14 to 12.

Another factory near Birmingham making electric motors, whose conversion was carried out some years ago, stated that belt wear has been halved, electric maintenance up a minute amount (in spite of the very large increase in number of motors), and that the actual number of motors out of commission with individual drive is intrinsically the same number as previously on group drive. Comparative power consumption is difficult to obtain because of varying conditions but readings taken over the same month of the year before and after the change-over in two consecutive years showed a ratio of power consumption to output, falling from 2 : 1.15. The following year showed a smaller difference, the ratio having risen to 1.51.

A factory in Scotland making heavy woodworking machinery had the interesting experience of changing from gas engine drive to D.C. drive, the old gas engines being used to drive the generators. The D.C. motors were then changed to A.C. motors still using group drive and then the large A.C. motors were replaced by small ones driving individually each machine tool. In changing to individual drive it was found that the machine tool makers' horsepower ratings were on the heavy side, resulting in a bad load-factor and before arriving at finality the sizes of driving motors were in some cases reduced to half, resulting in a gross reduction of about 30% on the total connected horsepower and, of course, a big improvement in power factor and efficiency. The shop at that time contained

about 80 machine tools and the owner reports that saving in power effected by changing from group drive to the individual drive was 3,000 units per week and as the cost of power was 1d. per unit the financial saving actually paid for the change in a few years' time.

From another angle the proportionate expenditure on electrical drive, power consumption, maintenance and investment charges varies between 2% and 4% of the total cost of production, whilst the cost of power alone varies between ½% and 2% of the total cost of production. The former set of figures checked up on a known factory changeover and allowing for recovery of half the cost of conversion in two years gave something of the order of 2% of total cost of production.

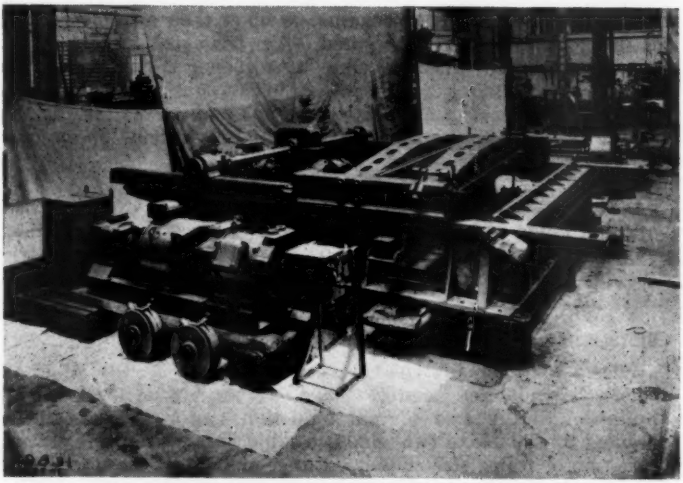

**Fig. 5.—Speed variation and reversals by motor operating from Ward Leonard M.G. set on Pickles reciprocating veneer slicer.**

A 50% increase or decrease in such a figure may easily be very much outweighed by the value of increased production and improvement of shop conditions. No two factories are alike in their working and conditions fluctuate so that accurate comparisons are difficult, but when every possible allowance has been made to discount such observations as given, the increase in power consumption would not appear to be a serious matter.

In comparing belt transmission of power with direct electric drive one engineer has expressed the matter very clearly and I think it is worth quoting. He said " Power in the line suffers no

appreciable loss, does not have to be lubricated, spoils no goods, is wearing out nothing, makes no noise and does not obstruct light. Here is power, over there is work to be done ; the gap can be bridged by mechanical devices or the power can be wired up so close to the work that no mechanical devices intervene. The net results have been :—

(1) Reduction in power losses of relatively minor importance.

(2) Reduction in maintenance and lost time cost, very marked.

(3) Choice of the best type of motor and control for each subdivision of the work—a matter of considerable practical value."

**Electric Drive.**

Machine tools which are designed for line shaft drive must depend entriely for their performance upon their own mechanical features. Any movement required, other than just turning round at a steady speed, must be done by mechanical devices on the machine tool. It is therefore interesting to consider what are the various characteristics of electric motors and how they can be helpful in simplifying, improving or initiating various operations.

**Speed Variation.**

As the motor drive is brought nearer to the actual work so speed variation tends to be transferred more and more to the electrical equipment. One of the most important advantages of electric drive lies in the simplicity of speed changing, either hand or automatically.

**Changepole A.C. Induction Motors.**

Where continuous stepless speed variation is not required changepole induction motors have a very wide and useful application. Any two normal induction motor speeds can be obtained by the use of two windings subject to the limiting output of the motor frame size chosen. Either or both of these windings can be arranged for reconnection in the speed ratio of 2 : 1 thus giving a maximum of four speeds. In motors up to 7½ h.p. the lowest economical speed is usually taken as 500 r.p.m. at 50 cycles, this being obtained from a 12 pole winding. The available speeds, therefore, from small motors can be chosen among those given by 2/4/6/8/10/12 pole windings, that is to say, no load speed 3,000/1,500/1,000/750/600/500 r.p.m.

A three speed winding must always have two speeds in the ratio of 2 : 1. The first speed can be any one of the others although 600 r.p.m. is not always an easy combination. Within the range mentioned, therefore, a choice of four speed winding is limited to 3,000/1,500/1,000/500 or, alternatively, 1,500/1,000/750/500 r.p.m.

Whilst such motors can, in the design stage, be arranged

to give either constant horsepower or constant torque, the actual tendency is for the motor to be more powerful at the higher speed even when designed to give constant torque. This characteristic is not altogether bad because though on machine tools removal of metal from large diameter work at low r.p.m. may be at the same rate as removal of metal from small diameter work at higher r.p.m. obtaining the same peripheral speed, and therefore, theoretically equal horsepower, yet the power required at the higher speed will definitely be greater due to increased friction and windage apart from actual productive work.

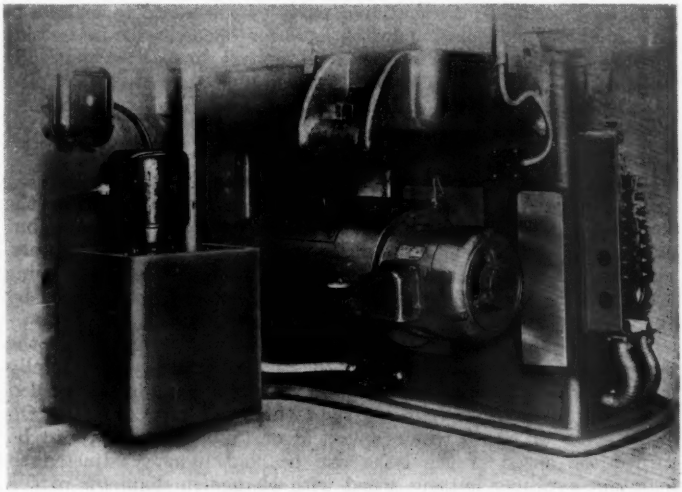

**Fig. 6.—Small combined Ward Leonard equipment mounted on base of Land cylindrical grinder giving 10 : 1 speed range on workhead motor.**

Where a four-speed motor is combined with a gear box and both first and second motion shafts made available for use, then a choice of eight speeds exists and this feature is employed in certain lathes and sensitive drills. One advantage is that the control gear can be so arranged as to make the motor speed change without risk of damage to the gear.

The Herbert No. 4SE has a geared electric headstock giving a total of eight speeds allowing a wide range for fine turning and boring in various material. The changepole selector switch is mounted on the top of the headstock, the " start " " stop " reverse" and " speed selecting " handles all being easy to reach and quick in

operation. Quick stopping can be done by plugging the motor momentarily into reverse.

A smaller type of capstan also of very pleasing appearance is the Ward No. OE. This also has a four-speed motor headstock. The changepole selector switch and "start" "stop," "reverse" control switch are built into the lathe bed immediately under the motor headstock, the two handles giving speed selection and "start," "stop," "reverse" are exceptionally easy to reach, being operated by girl labour without fatigue. The contactor giving reversing and protection is mounted on the inside of the hinged door to a cabinet formed in the leg of the lathe and the door itself is interlocked so that live parts of the contactor cannot be exposed until the isolating switch has been opened. An interesting feature of this machine is the mechanical brake automatically applied every time the control switch is brought to the "off" position. The illustration shows that accessibility of the control gear in this case is superior to that of many separate switches.

## Variable Speed A.C. Commutator Motor.

The speeds of A.C. motors are in general governed by the number of poles and fixed by the frequency of the supply but stepless speed variation is obtained from A.C. Commutator Motors. A very wide range of slepless speeds can be controlled by moving the brushes on the commutator either by means of a lever or by the use of a pilot motor.

A.C. Commutator motors tend to be somewhat large and at the present moment rather costly but they have been very successfully used on wheel lathes where different speeds are required, coupled with the possibility of reducing the lathe speed very quickly. On other types of lathes where spherical or taper forms have to be turned the speed of the lathe can be continuously adjusted to maintain a proper cutting speed with change in diameter of the work. Inherently the motor gives constant torque but its full load to no load speed regulation is comparable with that of the D.C. shunt motor. Where constant horsepower is required the size of the motor tends to become rather large.

## D.C. Motors.

Stepless speed variation is a well-known attribute of direct current motors whose speed is easily changed by altering the strength of the shunt field using a rheostat. This gives the constant horsepower output so highly desired for machine tool work and small speed drop between no load and full load which is called shunt characteristic. Although for small powers speed ranges up to 6 : 1 have been obtained, the usual limit is 3 : 1, and this becomes more difficult to get for outputs of 25 h.p. per 1,000 revs. and upwards.

Shunt characteristic is wanted for most work but for such duties as feeding, traversing, elevating, etc., needing heavy starting torque, frequent starting, stopping, or reversing, and where the load can never come off altogether, then series D.C. motors can be used. As on crane motors, speed may be controlled by inserting variable resistances in series with the armature. It is a wasteful method because the main line current passes through the resistances and in reducing to half speed half the total power used is wasted in heating up the resistances. Since this condition is usually intermittent it is tolerated for the sake of convenience and to obtain series motor characteristics which are ideal for certain applications. As a method of speed variation series resistance control is a crude method of regulating the voltage, and it permits the motors to give only constant torque over its speed range with the disadvantage that change in load causes the speed to alter.

**Infinitely Variable Speed.**

A more efficient method of varying the speed by voltage control is the use of the Ward-Leonard generator set. This is composed of a driving motor, a direct current generator and an exciter. The generator supplies current at an adjustable voltage and the speed of the spindle motor is very efficiently controlled by varying the strength of the generator field and consequently the motor voltage. By reversing the polarity of the generator field current stepless motor reversals are easily obtained. By a simple adjustment the control gear can be set to give any desired forward speed and to return automatically at some different usually higher speed.

Ward-Leonard control is very widely used for rolling mills, pit head winding gear, excavators, metal planing machines, woodworking veneer slicers of the reciprocating type, and in smaller sizes for operating workhead motors (and sometimes also the wheelhead motor) on certain types of grinding machines.

Cylindrical grinders commonly have a small motor ranging in output from about ½ up to three h.p. for rotating the work. To accommodate different diameters of work a very wide range of stepless speed variation is necessary and the direct current motor very conveniently gives speeds ranging between 4,500 r.p.m. down to 400 or 500 r.p.m., theoretically going down to zero. These workhead motors are supplied from small Ward-Leonard sets, and the Lund grinders shown use a complete motor generator exciter set compactly mounted on the back of the grinder bed.

A somewhat similar arrangement is used on a well-known thread grinder but in this case not only is the work rotated by a variable speed motor but also the grinding wheel allowing correct speed to be very easily maintained, compensating for wear of the wheel and

also giving the best low speed for dressing, each motor being operated from its own independent generator.

On the Lund grinder in addition to the three machines comprising the Ward-Leonard set, the work is driven by a separate workhead motor, the lubricant pump has its own self-contained motor, and a further motor is used for the hydraulic pump. The wheel is driven by a motor and sizing of the work can be done with extreme accuracy by the use of a photo-electric cell. Optical methods of measurement are, of course, well-known but here on a production machine the operation of a beam of light on a photo-electric cell not only indicates when the finished size has been reached, but stops the feed.

The ease with which speed variation can be controlled on direct current motors has led to the use in some cases of rectifying valves for converting from alternating current to direct current. On the Kendall and Gent vertical milling machine shown the table feed motor and elevating motor are squirrel cage A.C. machines but the spindle motor is a direct current machine with stepless speed variation between 700 to 2,100 r.p.m. taking the supply from the rectifier. By the addition of a three speed gear box the infinitely variable speed range is extended from 35 to 1,000 r.p.m. The output of the spindle motor is 6 h.p. over the whole range with shunt characteristic.

**Built-in Integral Drive.**

The greatest progress in machine tool design can only be fully reached by bringing electricity into close combination with the working of the machine instead of regarding it as some external separate auxiliary.

An integral drive permits more power to be available as and when required and the transmission of power directly and solidly along the spindle avoids all the limitations which are imposed by belts upon power and speed. Modern induction motors can be designed to run efficiently at average loads, whilst at the same time having in reserve a capacity for big overload torques to take care of peak demand. This capacity is there when wanted but until required it is not consuming any frictional power nor any extra belt wear.

The endshield mounted motor direct coupled is almost but not quite an integral drive and perhaps the most important factor in this development is the use of induction motor stator rotor units built round the operating spindle and carried in frames forming part of the machine tool. They thus fit into the position most advantageous to the duty required. On certain classes of machine tool it is awkward, inconvenient or even impossible to transmit auxiliary movements mechanically from one central point and simple squirrel cage induction motors built in at the exact point where power is required do overcome many problems in design, making the machine tool much more simple both in construction and in operation.

The large woodworking tenoner exemplifies this point. The White machine has altogether fifteen motors capable of being adjusted for linear and angular movement. The motor shaft is also the tool spindle and the machine designer's bearing and end bracket are entirely special, for which the standard industrial type of motor would be entirely unsuitable.

The built-in type of motor has been criticised as being difficult to replace should breakdown occur but in practice the contrary is often true. Motor units have been standardised to almost the same extent as the industrial complete motor but the units have the advantage that for any given output and speed the same electrical stator can be put into any number of different and special frames. However much the external shape of the motor is altered the housing for the stator is common. The stator, which is the only part destructable in service can usually be changed almost as quickly as replacing a complete motor even when a motor of correct size and speed is available.

Whilst the use of built-in stator rotor units found its earliest and more obvious beginnings on woodworking machines where working speed are particularly suitable for direct induction motor drives, the built-in unit particularly of the changepole and high frequency type is finding a very definite position in modern metal working machines. There can be no doubt that the elimination of belts and the mounting of the motor directly on to the operating shaft does remove one source of weakness in the machine and danger to the operator.

**Choice of Rating.**

In designing an all electric machine tool, duty cycles need to be very carefully observed and correctly interpreted. The average heating resulting from a period of peak loads or current inrushes must be considered together with the reserve capacity needed by the motor to deal with the maximum torque demand of which the machine tool is capable. As the drive becomes more and more individual so rough and inaccurate methods of guessing horsepower must be eliminated. Motors too large are costly, inefficient and sluggish whilst motors too small lead to overheating, breakdown or limitation of output. Correct choice of motor, type of enclosure, rating and details of control can best be ensured by collaboration between makers of the machine tool and makers of the electrical components. This collaboration to be effective must include representative views of the Production Engineer.

**Enclosure.**

Enclosure of motors is a matter of great importance and whilst ventilated motors are generally satisfactory yet total enclosure is excellent in giving protection to vulnerable parts. In certain situ-

ations where metallic dust, oil or dirt can get at the windings total enclosure becomes essential. Size and price are, of course, increased by total enclosure but these disadvantages can be kept to a minimum by careful study of the duty cycle, conditions of operation and particularly by external methods of cooling. Cooling of totally enclosed motors depends upon external radiating surface and is helped by direct contact of considerable masses of metal.

Ribbing the motor frame gives a valuable increase in radiating surface and cooling is further improved by using an external fan. Under favourable conditions an externally fan cooled motor will be capable of 80% of its ventilated rating. Intermittent operation is of great help in the case of totally enclosed motors and it is true that the majority of machine tool duties can, from the point of view of the motor design, be regarded as intermittent. This applies not only to such obvious cases as drilling but even to many lathe operations.

Speaking broadly, if the motor is to be ventilated it can be rated at a fairly high horsepower on a short time basis. On the other hand, where a totally enclosed motor must run continuously although intermittently loaded then its horsepower rating had better be kept to the lowest safe value and the utmost use made of its overload capacity.

## Reversing and Plugging.

Small induction motors can be quickly stopped by " plugging " or switching into reverse to obtain high braking torque, then opening the circuit just before reversal actually occurs. Reversing of motors, usually for tapping, is best known on the Asquith and Archdale radial drills. Thirty reversals or 15 tapped holes per minute is a popular figure. The permissible number of reversals depends more upon the heating of the motor than on the physical time taken, and heating is a function of speed and weight of moving parts. This is clearly illustrated by he case of a small changepole motor which at speeds of 3,000/1,500/1,000/500 is limited to 1.5/4/14/40 reversals per minute respectively, this limitation being due to the inertia of its own rotor without any external load.

Changing the material of a heavy chuck from steel to aluminium in another case very materially increased the permissible number of reversals at 3,000 r.p.m., whilst arranging the control gear so as to pass through the 1,400 r.p.m. speed before switching on to the 3,000 r.p.m. speed made an improvement of 38%. Reversing should always be done at the lowest possible motor speed and external inertia kept to a minimum.

On D.C. motors dynamic braking can be very accurately controlled. The motor is stopped by connecting resistance between

its main terminals (which are disconnected from the line). The motor then generates current through the resistance by using up its stored energy and thus quickly stopping. The field winding is frequently left continuously in circuit. This principle is very successfully used in the Butler patent electric feed to slotters and planers.

## High Frequency.

For high speed work the induction motor with squirrel cage rotor is almost ideal because it has no winding or commutator to get out of balance or to wear away or be maintained, and high speed obtained by the use of high frequency permits the drive to be made by motors built directly around the final spindle, free from any intermediate belt or gear. This construction avoids side stresses while its simplicity ensures long life and freedom from all transmission troubles. Speeds of 24,000 r.p.m. operating from 400 cycles and even higher speeds, the drive by high frequency motor taking its supply from a frequency changer, have been in service for a number of years performing the operation of wood routing. The experience thus gained prepared the way for the design of metal working drills with motorised spindle, which can thus be arranged to run at the most efficient drilling speed. Such a sensitive drill is operating at about 11,000 r.p.m. from a 200 cycle frequency changer and is drilling .025 in. holes. Incidentally, this frequency of 200 cycles is in very general use for operating portable tools.

An interesting application of high frequency drilling exists in the works of Messrs. Jos. Tucker, of Birmingham, who manufacture lighting switches and accessories and it arises from their dissatisfaction with an old method of drilling the dollies for tumbler switches. The switch rocking pin passes through a hole in the spherical portion of the dolly. Upon the truth of this hole depends the satisfactory operation of the switch and it was found difficult to avoid a considerable percentage of rejects when drilling straight through from one side to the other. They therefore designed their own drills, using built-in high frequency direct drive induction motor units, operating at 8,700 r.p.m. supplied from a small frequency change of the single unit type.

The new dolly drill consists of two horizontally opposed drill heads, the average size of hole being $^1/_{16}$ in. The dolly is dropped into a jig and held by foot-operated clamps, the operator pulls down the sensitive lever and the two drills advance simultaneously, drilling from opposite sides of the dolly, breaking through into a central hole at right angles. Operation of another pedal unclamps and ejects the dolly ready for the next. Using this type of machine, the two holes are drilled simultaneously with the precision of a boring machine. The alignment of the head is so perfect that the right-hand

drill may be allowed to run into the hole made by the left hand drill without any visible mark or shoulder. Drills which formerly needed regrinding after every 4,000 operations will now cope with 40,000 parts without regrinding. There is practically no maintenance and the battery of machines has been in service for three years without a moment's trouble reducing the cost of the operation by at least 50% and what is perhaps of even greater importance, made that production much more accurate.

**Frequency Changers.**

The induction type frequency changer is virtually a slipring induction motor. If its rotor is held stationary and its stator excited from, say three-phase 50 cycle supply, the machine will act as a transformer giving 50 cycle ouput from its slipring. If then the rotor is made to turn against its rotating flux the slipring frequency will rise and at full speed in reverse direction the output frequency becomes 100 cycles. Frequency changers can be designed for any desired frequency and can be provided with means, such as variable speed drive, for adjusting the high frequency. At outputs of 150 cycles and above, reversing the excitation to the stator reduces the high frequency by 100 cycles and the voltage in the same proportion.

**Control Gear.**

The function of control gear is primarily to make and to break circuits and to afford protection both to the apparatus which it controls and to the source of electric supply. Control gear varies from a simple switch making a connection with an electrical supply to a complex arrangement of contactors, push buttons, plungers, brake magnets such as are used in operating metal planing machines, slotters, special types of drilling machines, boring machines, and millers. For example, by accurate control gear timing, the feed of a Butler slotter is made to step forward every time the ram reaches the top of its stroke, the motor being started, run for a definite number of revolutions, and stopped.

Use of the contactor which is a switch, single pole or multi-pole operated by an electro-magnet, is becoming universal. Contactors can be remotely operated by means of a push button or pilot switch and the push button or pilot switch in turn can be operated at adjustable points on moving parts of a machine by the use of levers or plungers, thus starting, stopping, plug stopping or reversing motors in any desired cycle. The Archdale traversing head line miller is shown designed for milling a row of pieces successively. Whilst the miller is cutting air between fixtures speed of the slide is automatically increased by adjustable dogs to about 240 ft. per minute. The dogs operate switches which start and stop the

quick traverse motors. It is interesting to note the different ways in which control gear is applied to various machine tools or even to similar machines of different makes. Two examples of four-speed sensitive drill, namely, that manufactured by Messrs. Herbert and Messrs. Pollard had in the former case a faceplate type of changepole switch mounted on the top of the motor head, whilst the Pollard drill uses a push button type of selector switch.

Two other drills, the Archdale and the Jones and Shipman, are again different; the Archdale drill uses a separate Igranic change-pole switch whilst the Jones and Shipman uses a built-in type of gear with a six position control, namely four-speed, an off position and a quick stop by reverse current braking.

Push button and pilot switch operation is common for plugging but reverse rotation relays are often used to prevent definite reversal of the motor by opening circuit just before zero speed. A plugging relay made by B.T.H. resembles a small motor and depends on the centrifugal action of weights opening the contactor circuit just before the motor would reverse. The Igranic relay is of the drag switch type having a belt passing over a pulley, the ends of the belt attached to a rocking contact. The motor must actually reverse a few degrees before the relay operates.

The timing of contactor operation is done in a variety of ways depending upon the time delay required, by tick-tock relays, grid-leaks, eddydrag relays or even by the use of small synchronous motors. One well-known automatic lathe uses a small synchronous motor driving a notched disc, the single phase synchronous motor taking the supply for its intermittent duty from a large contactor coil, which is tapped to give the correct voltage.

The Butler feed drum is used for measuring and controlling tool feeds on slotters and planers. Movement of the ram or table closes a relay circuit starting the feed motor to which the drum is also geared. When the first tooth on the drum strikes the relay plunger it is forced up, opening the contacts which causes the motor to be dynamically braked to rest. A little as half a rev. of the motor can be controlled with accuracy and feeds as fine as .002 can be obtained.

## Future Developments.

The progress from mechanical to electrical means of operating machine tools is being carried on by research and it is certain that in the immediate future machines will be operated and controlled by even less tangible methods by use of photo-electric cells and thyratrons. The photo-electric cell is not only sensitive to the difference between light and dark but to gradation of light and colour. The current given out by the photo-electric cell is minute but can very conveniently be utilised when linked with a thyratron.

Various operations can be controlled, such as motor speed variation, by changing the quality of the light thrown on to the photo-electric cell. Thyratron tubes are used on welding equipments and may in the future occupy an important place in controlling and timing motor reversals and speed variation.

## Conclusion.

Whilst every factory will work out the drives best suited to its own particular needs it would appear that in many installations using line shaft drive, production could be increased by individual drive and the points may be summarised : (a) Ability to arrange the individually motorised machines to suit the type of work and to change the position quickly to meet changing working conditions ; (b) to lessen wholesale interruptions due to breakdowns ; (c) the operator feels safer, gives less attention to the actual drive, whilst electric control is less fatiguing ; (d) where elaborate or complicated control of the individual machine is desirable ; (e) where remote control is used thus leaving the operator free to observe the work ; (f) by closer speed regulation through reduction or elimination of beltslip, giving higher average speed ; (g) where the speed of the individually motorised machine is adjusted to the best speed at each part of the works cycle ; (h) where the tool on the motor spindle complete needs linear or angular movement.

It should be considered whether even a small increase in production may not amply justify initial investment and a large percentage increase in those items chargeable to the cost of the machine tool drive.

## Discussion.

MR. H. A. DRANE (Section President): We have listened to a very interesting paper by Mr. Batchelor and he has covered quite a wide range of the applications of motor-drives. I think probably it would now be a good opportunity for our electrical engineers to rise and shine. Mr. Batchelor, I am sure, will be very glad to answer any questions or enlighten us on any particular points.

MR. CAULTON: During the paper Mr. Batchelor mentioned that the cost of conversion varied from £10 to £35. Is that the cost of the electrical conversion, or does it also include the cost of mechanical alterations to machines? If not, would Mr. Batchelor give us some idea as to the proportion of the cost for alteration to a machine in comparison with the cost of the electrical gear?

MR. BATCHELOR: The figures given could obviously be only very rough, because they depend upon the size of the machine, but they do include work done as well as the cost of the machine. The percentage of a new machine—a wood-working machine—would be 25 to 30% for electrically-driven machine over the cost of a belt-driven machine. Changing over drilling machines, using a 2 h.p. motor, small contactor and push-button, the ratio of cost of the motor and electrical gear was something like 6 to 2. Taking a particular case: There was a machine on a Coventry scrap-heap—a Profiling Miller—which was acquired for practically nothing. Two motors were fitted on it at a cost of £25, the ratio of labour to material being half and half. The motor and control gear that was added cost about half and the cost of modifying the tool cost the other half.

MR. DRANE: There is then a very big variation.

MR. CAULTON: Taking the whole of the machine shop, what would the percentage be?

MR. BATCHELOR: Something in the order of 20%.

MR. DRANE: I think we all appreciate the real advantage of a motor-driven machine, but on a number of the machines you illustrated you were still troubled with the shape of the drive, and also I believe all the drives where you had a motor coupled to the machine were by belt. Have you any experience of a short belt against a chain or a texrope?

MR. BATCHELOR: If I were asked to choose between the three, speaking generally, I should choose the texrope. I know that this has certain disadvantages, in that one rope sometimes starts slipping and stretching. We used to use chain, but this we found would not stand up to the job. On a certain job, a case of a frequency change over, the motor was somewhat small and put a big strain

on the gear; we put in a vee rope drive and this worked very well indeed.

MR. DRANE: You favour texropes?

MR. BATCHELOR: Yes. That seems to be the opinion of a good many people.

MR. DRANE: There was a small Precision Grinder I heard of the other day, which was originally belted up with vee belts. It was rather a short drive, and actually on this machine these ropes were not successful; I could not understand why. I didn't actually see this machine, you understand. A small flat belt was designed and put on the machine and this did actually do the job. I think it was a direct coupled motor, and they were troubled with vibration—probably one belt had stretched more than another.

A MEMBER: Would Mr. Batchelor give us a little more detail on the photo-cell sizing device, and what limits of accuracy are obtained.

MR. BATCHELOR: The photo-cell can be taken as having similar limits of accuracy to any other light system of measurement, as, for example, the Zeiss method. It is a method similar to a lever where you can change the ratio; it is an easy method of getting a very big ratio in movement by using a beam of light instead of a mechanical arm. The particular one I was speaking of worked to about $^{2}/_{10}$ of a thou. You have a slit with a beam of light; you move your arm so that your cell comes in line with the beam of light; a current is created and that operates various relays which stop the machine.

MR. DRANE: Is that system employed on planing machines? Where you mentioned half a revolution, how do you guarantee the half revolution? On an ordinary machine when you want to stop it you always go into reverse.

MR. BATCHELOR: It is done in practice by the adjustment of the contactors. I believe it takes a fair time on almost every machine to make the final adjustment of the contactors. When the ram reaches the top of its stroke the relay pushes in the contactor which starts the motor forward. Reversing is effected by dynamic breaking.

MR. DRANE: Actually, then, there are two actions—one to start the motor and one to stop it. Actually on this machine they have a solenoid as well? As the table reverses the solenoid makes contact and lifts it up?

MR. BATCHELOR: Yes.

MR. POTTS: One of the antiquities of Coventry that we don't boast about is our two-phase power supply. In that connection I would like to ask what is the efficiency of pole change motors on that supply. I think it is about 60%, but would like to be sure. Also I want to touch on chain drives. Mr. Batchelor gave a number

of illustrations of drives and mentioned that most drives are necessarily at short centres. He also touched on bearing loads. Also, with reference to the small, old, Coventry machine, this obviously was a case where a centrifugal clutch was required. I would like to put in a word for the virtues of chain drive, which is positive yet with a certain amount of elasticity. With regard to the question of safety and cleanliness touched upon, I would like to support that. We find by taking old belt drives away and completely modernising the machines, putting cast-iron guards round the machines to form part of them, the operators not only feel more content, but take more pride in themselves as well as in their machines, and the net result is very encouraging to all concerned. You stressed the point about motors being the correct capacity. I am curious to know if it is possible to state precisely what power any one machine in a whole shop requires.

MR. BATCHELOR: Taking the last point first. You must have a meter on each individual machine. Re change pole motors on two-phase supplies. In Germany they won't build two-phase motors; they insist on your putting in a little transformer. Two-phase change pole motors can only give about half their 3-phase power, and are extremely difficult to design. Your point about chains was very interesting. You have got to design the chain drive properly, and in high-speed work it has very definite troubles. Lubrication becomes very much more important, and the job of keeping the oil in the gearcase is another difficulty. A belt drive is an easier thing to apply. It doesn't call for as much skill in design. Don't you agree?

MR. POTTS: You have more adjustment and it fails earlier.

MR. ROBERTS: I met Mr. Batchelor, I think, first as a competitor, then as a colleague, now as a customer, and to-night I am meeting him as a critic. There have been many extremely interesting points, but I don't think I agree entirely with him on many of them. First, group and individual drive. I think we really don't want to concentrate on either the one or the other, but a judicious mixture of both. Mr. Batchelor just touched on that particular aspect and said that in many of the modern factories the best arrangement for production will probably be found by having, say, three rows of machines, the centre one of which would be individually driven, the two siderows being belt-driven. By belt drives in that case I would confine myself not to countershaft drives but to single pulley drives with geared headstocks (taking of course the lathe drives). The individual motor-drives give you the flexibility for overtime work. At the same time, the individual motors definitely give you a far greater loss in power than the belt drives. That is particularly the case when you consider the mean value of the power taken for the whole day. If you had, say 20

machines working in a bay you would not consider putting anything less than 2½ to 3 h.p. motors on each one of them. They might take up to 40 or 60 h.p. on individual motors, but if you drive them with one grop drive you would not put anything more than 25 h.p.

You would run that motor on a very good load factor. The individual motors, if you run on individual drive, would have a very low power load factor on account of your tool power being taken intermittently, where as on the group drive those small individual variations are absorbed on the total load. Your constant control gear is reduced; the cost of motors is also reduced, and I think you will find that whereas in the States they were very keen at one time on individual drive the tendency these days is to go on to the group drives. The States have found they have had to economise, and in consequence they have investigated every avenue for economical running.

Another point. We can recognise the fact that in many special drives, such as planers, slotters, millers, the individual drive has many advantages and enables the control of your machine to be very much simplified. It also enables you to place your machine geographically in a position to increase production to a far greater extent than any belt drive, but there are other machines, i.e., internal grinders, where the multi-drive spindle produces ripples on the work, which the belt-driven spindle does not do. You will find that on a number of the modern German machines the spindles are belt driven and not driven direct by the motor. The trouble seems to be one of dynamic balance, and no matter how careful you are in regard to the balance of the rotor it does produce a ripple. I would like Mr. Batchelor to mention what he considers the better bearing in regard to the motors—sleeve or ball. The tendency is to go on ball bearings, and in Germany and the States to revert to the sleeve bearing. Another point is the fact that you refer to "texrope" drives. I am sorry, but that is a misnomer. "Texrope" is a trade name, and we should keep to vee rope.

Mr. Batchelor mentioned lower maintenance cost for running individual drive against group drive. I think he might have stressed the fact that that is only obtainable if the control gear is carefully chosen. There is a good deal of cheap control gear on the market which does not add to the reputation of the motor-drive. Another point is the reliability of the small motor as against the large motor. I don't entirely agree with Mr. Batchelor since I think the large motor has a good chance in regard to its greater clearances. Similarly, with the control gear. The small clearances on the 1 h.p. and 2 h.p. contractors are so small as to make it difficult for the wireman to wire a job efficiently. With the new materials, i.e., moulded bakelite, I think it causes unnecessary trouble which on the part of the electrical manufacturers could be almost elimina-

ted. In closing, I would like to refer to the chain drive as mentioned by one of the speakers, and that to my mind has very serious disadvantages. The main disadvantage, I find, in regard to the chain drive, is that you have no safety factor. You protect your motor by means of control gear, overload coils, etc., but you cannot prevent a bad job at times on the drive. With the chain drive there is no means of taking up that sudden lessening of inertia that you get from the rotors, whereas with a belt drive you either get the belt slipping or coming off altogether, or perhaps breaking.

MR. BATCHELOR: Mr. Roberts says I speak as a critic—on the contrary, I have been over the shop which Mr. Roberts equipped and I was filled with admiration. I didn't think it would be possible to instal a line-shaft shop as neatly and cleanly as Mr. Roberts has done, but that does not affect my opinion on the whole matter. In passing, I might say my paper was on the *elimination* of the belt drive. Mr. Roberts mentioned the costs, which I had already dealt with. The figures given you were taken from three shops in different parts of the country, and in two cases they were actually figures taken as a ratio of the production.

MR. ROBERTS: Were they taken on machine shop tools or textiles?

MR. BATCHELOR: Machine shops.

MR. ROBERTS: Modern?

MR. BATCHELOR: They had been modernised; the machine tools were mixed. When the second set of readings were taken the same old machines were there but they were individually driven. I also dealt with that aspect by pointing out that the cost of installing the machines and of running them may be taken as between 2 and 4% of the total cost of production. If the Americans are depending on that for economy they cannot be effecting a very big economy even if they saved the lot. Dealing with the question of ripples. That has been a definite trouble on wood-working and on grinding machines, but I believe it is being entirely eliminated, and whilst I agree that dynamic balance has a lot to do with it I think the point is very often mixed that bearing fit is of just as much importance as dynamic balance. You mentioned that the Americans favour journal bearings. The Norton Grinding Co. issued a bulletin recently saying that for all normal grinding ball bearings were suitable, but they recommended journal bearings for a super finish. We recently took some vibrometer tests on two motors, one having ball bearings, the other journal bearings, and we could trace very little difference on the vibrometer. I think it is quite reasonable to suppose that balls tend to produce markings on the work, but I think it is still a matter for investigation. Maintenance. The experience of at least one factory was that maintenance costs are lower. The maintenance of the belts

was also lower. Maintenance of the machines themselves was up, but only by a very minute amount probably something like 2 or 3%, and although we took out perhaps 18 motors and put in some hundred the total number of machines out of commission was exactly as before, which, I think is an interesting point. Mr. Roberts's remark on the design of small motors and control gear I think is entirely justified, but I don't think it affects the main issue to any appreciable extent.

A vote of thanks, proposed by MR. CORBETT, concluded the proceedings.

# PROTECTIVE METALLIC COATINGS BY THE WIRE SPRAYING PROCESS.

*Paper presented to the Institution, Southern Section, by Major H. J. Williams, and read at the Luton, Bedford, and District Section by W. E. Ballard.*

THE commencement of metal spraying was a patent by Dr. Schoop taken out in Switzerland in the year 1909. The patent was for an apparatus in which a stream of molten metal was brought into contact with a stream of gas at high pressure and was caused to split up into a fine spray in which was placed the article to be coated. The apparatus was much too cumbersome and could not by any means be considered as a mobile commercial unit. In the following year a patent was taken out by the same inventor and his associates for an improvement of this idea in which the apparatus was made more portable, because instead of molten metal, powdered metal was used. This was passed through a blow-pipe flame, some of the powder metal particles became melted and were sprayed forward. The apparatus had certain disadvantages and eighteen months later Dr. Schoop produced the first pistol for spraying solid metal. From that time onwards the development of the process was entirely confined to the spraying of solid metal in wire form.

During the past few years the success of metal spraying by the wire pistol has caused the attention of certain firms to be directed to the older methods, those of spraying fluid and powdered metal, but the disadvantages of these systems are still very much the same as they were with the original inventions. The disadvantage of the fluid metal spray is that as the pistol itself has to have a container holding fluid metal it cannot be used in every position, and, furthermore, difficulties of construction make it almost impossible to spray metals of high melting point.

On the other hand, the powder system is completely mobile and is comparatively easily worked, but no method has yet been found whereby it can be assured that all the powder passing through the flame is molten at the time it is sprayed. This fact brings about a modification in structure which is far from desirable and will be referred to later. In view of these facts it cannot be disputed that the wire pistol still holds the field as being the most universal tool and, therefore, this lecture will be confined to metal spraying by the wire system.

*Southampton, November 18, 1936; Luton, January 5, 1937.*

The actual construction of the wire pistol is now so well known that it is my intention only to give a very brief description. The pistol usually consists of a die-cast aluminium case which contains a valve for the control of the gases which feed the pistol. These gases are three in number, the propellent gas which is usually compressed air, the combustible gas which may be compressed coal gas, hydrogen or dissolved acetylene, and the third gas, which is oxygen delivered from cylinders. This latter is required to give sufficient calorific intensity to the flame. The three gases are controlled by one valve and the combustible gas and oyxgen pass from it straight to the nozzle. The valve also divides the air stream into two streams, one passing to the nozzle where it is used as the propellent, and the other to the back of the pistol so that it may drive a small air turbine. This turbine normally rotates at speeds from 1,200 to 3,000 revs. per minute and its function is to drive a system of gearing which in turn pulls the metallic wire from a suitable spool and pushes it through the nozzle at an even pace. The wire is usually from 1 to 2 mm. in diameter. The combustible gas and the oxygen pass into the small mixing chamber in the nozzle and when they are thoroughly mixed they pass down annular flutes situated round the wire nozzle and at the end of this nozzle they burn in the form of a blow pipe flame. The compressed air is conducted through a surrounding nozzle so that it issues from the end encircling the flame containing the wire. It will be obvious that then the wire reaches the hot zone of the flame it will melt off immediately providing that the wire speed is correct. The small drops of metal will be caught in the compressed air and shot forward as a spray. In most cases the spray is so fine that it cannot be seen. As a guide one might say here that the volume of compressed air required is about 15 cu. ft. per minute and is usually used at 50 lb. pressure. The gas and oxygen usually vary in pressure from 15 to 30 lb. per sq. in. and 30 cu. ft. per hour is about the maximum volume used. The wire pistol has a distinct advantage in that the nozzle may be adjusted by putting on long lengths of tube and by means of special apparatus so that it may be adapted for the spraying internally of tubes down to $1\frac{1}{2}$ in. internal diameter. So far as I am aware the wire nozzle is the only metal spraying tool that is capable of being adapted in this way. Before passing from the apparatus used in metal spraying, it might be mentioned that it is possible to spray small articles in a tumbling barrel of special design by putting the pistol at an angle into the barrel. The results obtained are not so good as when articles are sprayed by hand but they are quite reasonable for nails, nuts and bolts, etc.

The pistol itself weighs about $3\frac{1}{2}$ lbs. and is therefore extremely portable, in fact the portability of the process is one of its chief assets because it is possible to spray metal on to all sort of work in situ-

for instance bridges, etc. Anyone who is not familiar with the tool can obtain further details from the makers or from the technical press and I, therefore, should like to pass on to a consideration of the process itself. As before mentioned, in the case of the majority of metals it is not possible to see the spray. In the case of iron where the particles, owing to their high temperature, are incandescent, the spray can be seen and by a study of the iron spray one can see what really happens. The point which should be borne in mind here is that the volume of gases which carry the comparatively small amount of metal have a large cooling effect so that the actual metal when it reaches the surface to be sprayed is usually without sensible heat. This enables the metal spraying process to be used for covering such articles as cloth and wood without danger of ignition. We have even gone so far as to spray slabs of gun cotton with copper without any serious effect.

Everything that has to receive the spray of metal must have a suitably roughened surface. The surface should theoretically be roughened to the same mesh as the size of the particles of metal which are produced. The particles of metal average about .01 mm. in diameter but the particles of the higher melting point metals are larger than those of the metals of lower melting point. In practice it is found impossible to alter the surface roughness in each case and so it is usual to strike the mean by preparing the metallic surface by blasting at 30 lb. per sq. in. pressure of air, and using angular steel grit of about 30 grade. In cases where it is impossible to use steel grit, flint sand is used but this is avoided as far as possible owing to the danger of the operatives contracting silicosis. It must be noted that the abrasive must be angular and not round.

If the metal sprayed is in the correct state when it reaches the surface it becomes at the moment of impact nearly molten if not quite fluid. The result is that the particles spread out into a ring form surrounded by a number of radiating splashes and if the metallised coating is to have the best properties the particles must all have this ring form and in fact they must all have been produced at exactly the same temperature and arrive at the base within fairly narrow limits of velocity. This velocity should be about that of a rifle bullet, i.e. 700 miles per hour. Owing to the rapidity at which the action takes place, the oxidation is not large and such metals as magnesium can be sprayed. In the case of the higher melting point metals such as steel, some oxidation does occur and the oxide occurs in two forms. One form is small oxide inclusions within the metal itself and the other form is an oxide skin on each particle.

The question is always asked " How does the metal stick ? " And it is very difficult to answer this question because none of the theories put forward wholly satisfy all the actual facts. The

adhesion is probably due to a mechanical interlocking with the pores of the surface to be sprayed and it is certainly not due to any form of alloying with the surface. The micro-structure of the junction always shows a clean but ragged line between the metal and the base. It may seem that such adhesion must be very weak but in actual fact this is not so. It is certain that a coating properly applied could not be wrenched from the metallic surface to which it is applied unless that metallic surface was strained above its elastic limit. Such an action does not occur in practice, for no structure is strained to this extent. Therefore theory tells us, and practice amply proves, that the adhesion is satisfactory for the majority of commercial purposes.

The industrial applications of metal spraying may be divided roughly into three classes : (1) The production of thin films of metal on all structures for such purposes as prevention of corrosion and the formation of electrical conducting films ; (2) the prevention of temperature oxidation, and ; (3) the building up of worn parts.

It is impossible to do anything further to-night than to make a very brief description of some of the applications.

The coating which has found considerable favour is that of zinc. This of course followed from the experience which had been obtained with hot galvanising, which has always been a favourite process for the prevention of corrosion. With zinc spraying there came a method of galvanising where large structures such as bridges could be galvanised in situ, and complicated and fragile parts which could not be treated in the hot galvanising vat could be treated with ease. Furthermore, metal sprayed coatings were of pure zinc and as such gave better electro chemical protection than the ordinary hot galvanised coating which contained large quantities of iron. It is particularly to be borne in mind that zinc coatings protect steel by electro chemical action of a sacrificial nature, that is they are in the right position of the electro chemical series. Metal sprayed coatings of pure metal are excellent for long protection. Furthermore, the thickness of the coating may be altered considerably to meet individual conditions. A coating of .004 in. in thickness is equal to the very best galvanising which can be obtained. Recently attention has been called to the fact that there is now available a very pure zinc for commercial purposes which is of such a purity that it was previously known in the chemical laboratory. Spraying is perhaps the only method by which reasonable thicknesses of coatings can be obtained with this intensely pure metal and therefore gives a method whereby the peculiar properties of this pure metal can be used commercially to protect other metals.

With regard to purity, the same applies, of course, to the metal aluminium, and extraordinarily good results have been obtained with aluminium coatings made with the super pure metal containing

99.9% of aluminium. Such coatings are resistant not only to sea-water but to such acids as sulphuric acid in fairly strong solutions Aluminium is used for decorative effects as well as for utility and has been used in the decoration of buildings with extremely good results because the aluminium gives a pure white colour. It has also been used in certain countries for the protection of the outside of oil tanks and this white colour serves in this case also to keep the contents of the tanks cool when in the direct rays of the sun. Much work has yet to be done on the optical properties of sprayed aluminium, but even at this moment in the film studios it is being used to obtain dead white effects.

Coatings of tin are, of course, used extensively in the dairy and milk industry and also in some chemical plant. It is sometimes possible to avoid the use of the expensive metal tin by substituting aluminium, but in some cases tin is the one metal which can be used, and metal spraying does offer a very good method of putting on thick coatings of pure tin.

The spraying of lead is perfectly easy scientifically, but much lead spraying is not carried out owing to the danger to the operators. Unless only a thin coating is needed it is usually better to use the process of homogeneous lead lining.

Coatings of copper, bronze and brass are used for ornamentation, but are not recommended for outside work because these alloys are definitely on the wrong side of the electric chemical series with regard to iron. Nickel coatings are used in cases where a very resistant finish is desirable and where a certain hardness is also required. Such a case is that of printing rolls.

If steel or iron be sprayed with aluminium to a thickness of about .006 in., and if this coating is heat treated in a special way, the aluminium will be absorbed into the surface of the steel, forming solid solution of iron aluminium and aluminium iron. These alloys are resistant to high temperature oxidation, and in fact this absorbtion of aluminium into steel was the foundation of the well-known Calorising process. The protection given to steel is very effective up to 950°C, and the method of spraying and afterwards heat treating allows very large vessels to be so treated, which is impossible with the older processes where parts had to be packed into a drum of aluminium powder. A particular case of the use of aluminising is the Air Ministry Specification for exhaust pipes. It is also used by the Admiralty for certain engineering problems.

Coatings of Nichrome are extremely effective where parts have to withstand temperatures over 1,000°C. Unfortunately, these coatings are very expensive, byt they are extremely useful in certain types of work and avoid the use of solid Nichrome vessels.

More recently the metal spraying process has been used for the

building up of articles with steel. The advantage of the process over welding is that the parts that are treated remain comparatively cool, therefore there is no likelihood of distortion. In building up worn parts it is desirable that the adhesion which is normal on sand-blasted surfaces should be increased in some way and it is usual in this case to treat the surface by turning on a rough thread on the surface to be built up with a tool placed below the turning centre. In cases of flat articles the surface is very often torn up by means of a planing machine, the idea is to increase the surface area so as to give a larger area for adhesion. By this means it is possible to build up automobile parts with steel, and so long as the parts are not subject to heavy shocks, the results will be perfectly satisfactory. Where parts have to withstand the wear of a rotary action the results are really remarkable. The hardness and properties of the steel film can be altered by various settings of the pistol so that it is possible to adjust the coating to the work which it has to do. The process has been used to a large extent for the building up of such parts as crankshafts of automobiles and the necks of rolls where there is not too great a shock. In finishing the parts so built up it is advisable to grind the surface to the finished size in preference to turning.

The structure of metal sprayed coatings is peculiar because it consists in the building up of millions of small saucer-shaped particles of metal and therefore in transverse section one gets a wavy structure and in a horizontal section a structure which consists of irregular-shaped units which are partially welded together. This structure means that the metal along its strongest plane is only as strong as a cast metal of equal dimensions but it possesses planes of weakness at right-angles to this direction. If turning is done with a blunt tool there is a liability for the cutting edge to pick out small particles from the surface giving a very irregular finish. On the other hand, with grinding, mirror finishes are obtainable.

With this somewhat rapid sketch of the possibilities of metal spraying I will close this paper, only again pointing out that metal spraying as an industry is increasing very rapidly and that the increase can only come about as the result of experiments and scientific thought. There is much yet to be done but the industry itself is no longer experimental, as can be seen from the fact that the annual absorption of aluminium in this industry is over 100 tons, and as aluminium coatings usually weigh about $\frac{3}{4}$ oz. per sq. ft., this means a very large area covered. The area covered by aluminium is quite small compared with the area that is covered annually by the metal zinc.

## List of Lantern Slides Shown.

Slide C. Pistol with valve removed.
,, D. Pistol showing turbine.
,, 2. Pistol nozzle in section.
,, G. Nozzle parts.
,, F. Nozzle body.
,, E. Pistol spraying.
,, J. Pistol end of extension nozzle.
,, K. Rotating end.
,, 6. Rotary nozzle specification.
,, 7. The rotary nozzle in use.
,, 4. The mass coating drum.
,, 737. Nozzles treated in the mass coating drum.
,, 25. Portable plant, Park Royal.
,, 13. Splashes of lead on glass.
,, 12. Iron splash.
,, 51. Transverse sections of zinc coating.
,, Microstructure of zinc coating.
,, Microstructure of powder zinc coating.
,, 617. Transverse section of steel coating magnified 1,300 times.
,, 54. The junction between zinc and steel.
,, 696. Aluminium on bronze junction.
,, 701. Bronze on iron.
,, 30. Viscose mixers sprayed with zinc.
,, 26. Anchors sprayed with zinc.
,, 543. Window being sprayed with zinc.
,, 723. Screen room sprayed with zinc.
,, 727. Spraying radio valves with zinc.
,, 33. Gasometers shelled before sprayed with aluminium.
,, 55. Gas holder.
,, 673. Hospital beds sprayed with aluminium.
,, 546. Mixing tanks sprayed with aluminium.
,, 722. Storage tank coated with aluminium.
,, 702. Laundry blanket dryers sprayed with tin.
,, 42. Impellor being sprayed with tin.
,, 37. Milk separators sprayed with tin.
,, 753. Pasteuriser sprayed with tin.
,, 43. Rolls sprayed with nickel.
,, Aluminised furnace.
,, 56. Microstructure of aluminised steel.
,, 55. Microstructure of aluminised cast iron.
,, 60. Aluminised road machine parts.
,, 23. Aluminised salt bath.
,, 544. Aeroplane exhaust manifolds being furnaced.
,, 521. The Atlanta.
,, 548. Method of turning thread.
,, 67. Thread itself.
,, 549. Spraying for building up.
,, 705. Microstructure of thread.
,, 68. Radiograph thread.
,, Thorman's results for wear.
,, Surface of turned coating.
,, Laboratory.
,, Oxygen content of copper coating.
,, Porosity of zinc coatings.
,, Carbon content of steel coatings.

## Discussion—Luton Section.

MR. W. PUDGE (Section President) : I feel we all appreciate the very able way in which Mr. Ballard has given this lecture, also the very frank way in which he has made clear the uses of metal spraying, both the advantages and disadvantages, because we can see that there is a great number of uses for it, but as he has said there is still a great deal to be learned, although it has passed the experimental stage. Metal spraying has been in hand about twenty-eight years, and certainly in another twenty-eight to thirty years there will be a lot more learnt about it.

MR. GATES : I have listened with the keenest interest to this lecture, although the subject was not entirely new to me. The lecturer has been extremely fair in pointing out the drawbacks and weak spots in addition to showing the useful points. Is the spraying process liable to variation in thickness, due to the variation in skill of the operator, and is there any easy method of judging the coating as it is put on and of obtaining the thickness and uniformity, as it would seem that the very thinnest coat would look very similar to a thicker coat ? As regards the structure of metal as it is laid down, that is also liable to variation from variations possible after application. Is there any means of judging the hardness of the deposit, which would be useful in cases of building up worn parts, as I should imagine it is impossible to employ normal methods because of the thickness of the coating ? As regards building up shafts in worn spots, is it possible to spray alloys or high carbon metals as well as mild steel, and would variation between the applied metal and the base metal have any serious result on the wearing qualities of the built up metal ? As regards coating tanks which are welded, there is always liable in electrical welding to be a certain amount of scale trapped, particularly in the internal corners. Is it difficult to get rid of that scale, and in coating the internal parts of a vessel would there be any difference in application or any greater reliability in electrical welding, oxy-acetylene welding, or rivetting ? Would you recommend either process as being more satisfactory generally for the application of spray coating ?

MR. BALLARD : As regards the first point, variation in thickness, it is comparatively easy to judge in bulk if a man is doing his work properly. You have a spool of wire and if you have to coat an article you know how much wire ought to be on it. You know the approximate loss through the pistol will be 15 to 20%, and you know the weight of wire it will take on the spool. You know the operator should put on that wire and you see that he does do it. This will

always be one of the difficulties with metal spraying. We usually go along when men are metalling and put a card in front of their pistol without them altering the speed and measure it with a micrometer. If we are doubtful we put a chemical test on some part of the job. The actual facts are that if a man has been working about a month he usually will not vary more than .001 in. up or down. If he does, you get rid of him. The human element must come in, but it is surprising how few defects you get from that reason. The structure will vary with the set of the pistol to a certain extent. You can tell by the flame and by the sound if the pistol is working normally, when you get an equal structure. If for any reason you want to alter the structure—as is usual for jobs such as building up, where you are not dealing with a thin coat at all, but dealing with a coat $^1/_{16}$ in. or $\frac{1}{8}$ in. in thickness—for those jobs you use the setting of the pistol which experience has taught you will give the structure you require. Very often that has to be found by experimenting. With regard to spraying alloys, it is absolutely possible. All alloys can be sprayed. In spraying zinc you lose 1% only, which is lower than any electric melting furnace, the reason being because the speed of the actual process is so great. With regard to alloys of steel for the result you want to get, if you spray high carbon steel you use high carbon coating and for low carbon steel low carbon coating. Actually, you get a slightly harder coating than the steel. On these hardened coatings it is practically impossible to take the hardness figures with the Brinnell or any of those hardness instruments where you use spherical indentation. When you are dealing with building up other metal you must not confuse wear with hardness, such as the actual curves of wear, if you take wear from the point of view of a shaft turning round against the journal or anything like that.

MR. GATES: I have in mind the possibility of the need of having some good hardness test for the coating.

MR. BALLARD: Hardness test would not give you anything, and a hardness test is not usual. You could do it with scratch hardness test or the Vickers hardness test. With regard to electric welding, the scale trouble is disappearing very fast. Actually, you get minute particles of scale being trapped, but they are knocked out by the sand blasting. Years ago we found that sealed vessels did have a very few scale enclosures. We reasoned with the welders and they said you cannot avoid it—but they are avoiding it, and there are few now so welded that you cannot spray them. Welding is always preferable to rivetting if metal spraying. With regard to kind of welding, it does not matter whether it is an electric or oxy-acetylene weld, provided both types of welding are good.

MR. MANN: If you have a case-hardened and ground shaft and it wears, if you build it up and rough turn it after you have sprayed

it, is it possible to case harden and grind after spraying and obtain good results ?

MR. BALLARD : Yes, it is possible, but it is never done in practice. The actual facts are usually these, that when case-hardened shafts wear down very badly they are usually turned with a Widia tool and the surface applied by metal spraying. You can do it, but then there would not be any use in metal spraying, because you might bring about distortion.

Replying to a question as to the relative merits of adhesion between metal spraying and the electro deposit method of building up a shaft, MR. BALLARD said : I would like to make that clear. Many people who do cheap electro depositing are not using the special feed process. When electro depositing is done without the special feed process the results are very much worse than metal spraying. On the other hand there are special processes such as where nickel coating needs putting on after special cleaning methods. In that case one needs atmospheric adhesion. The results are, to a certain extent, better than those obtained by metal spraying. Actually, the adhesion of special clean electro deposit coating is slightly better than metal spray coating. If you want worn parts to resist shock as well, I should have the electro deposit process.

MR. HOLLOWAY : You made special stress that before treatment the surface must be roughened. In process of spraying the barbs are going to be filled in in time. Taking some of the samples round the room, in the grinding and furbishing process do you not lose some of the adhesion, and the barbs flatten out ?

MR. BALLARD : I am not quite clear as to what exactly you mean, but if you take a barb such as I have shown, they are very tiny, but metal spraying is all round it, therefore there is no question that they flatten out in the actual grinding processes afterwards. Actually the roughening has no effect on the correct grinding afterwards. You can, of course, spoil a metal spraying or electro deposit job very easily. Say you take a roll which is 1 in. in diameter, if you grind that with heavy pressure with a stone which is 1 ft. in diameter, then you have every possibility of enlargement. If you are going to grind a crankshaft you grind it with a certain amount of common sense, if you grind in the ordinary way there is no danger of altering adhesion even in electro deposit or metal spraying.

MR. HOLLOWAY : In the spraying process you naturally fill up the hollows ; equally then you cover the barbs ; by so doing you lose your roughened surface to a great extent. If you lose your roughened surface at all it would appear that the process is nullified to a great extent.

MR. BALLARD : No. If you take a half-crown and sand blast it, then metal spray it to $\frac{1}{4}$ in. thick, you will still see a semblance of the letters on the coin. Metal spraying has that curious property,

it always takes the exact surface it starts with. You will not get barbs showing through, because they are very tiny, but you will get thread showing through and that has to be ground up afterwards.

MR. HOLLOWAY : With the barb still in position after metalling the result of the indentations would appear to be rounded.

MR. BALLARD : I think you are probably getting a little mixed owing to the detail being shown so big on the slide, whereas it is in fact very small, and it should be remembered that the thread was about 5 thou. deep and the barbs were within that thread, so that the barbs were rather less than 1 thou., the little metal saucers being about $^1/_{100}$ mm.

MR. HOLLOWAY : Is any other method recommended other than spray blasting or shot blasting ? Also you mentioned that various gases may be used for spraying wire. Would it be suitable to use town gas ? What would be the recommended pressure for using compressed air ? As regards the guns you recommend for wire spraying, are they suitable for any type of wire spraying and could some idea of the cost of the gun be given and the cost of installation ?

MR. BALLARD : It is necessary to create a rough surface and it could be obtained by means of etching, but it is not a commercial proposition. In the old days the blasting process used flint sand, but the use of flint sand is not recommended by the Home Office and therefore we changed on to the next best thing, which is angular steel shot. Definitely, sand is better than shot. I am sorry I did not make it clear that any gas of sufficient calorific intensity is used and at our own work we use all town gas. The town gas is taken from the main and is compressed at 30 lb. per square inch pressure. That pressure of gas is used for all metals. With other gases, when you use gas from a cylinder you alter the pressure of the gas. We use this town gas at 30 lb. pressure. Air pressure between 45 and 50 lb. per sq. in. in this country, and in Germany they use about 30 lb. per sq. in. The wire pistol I have shown is applicable to all metals up to Nichrome. It can be adapted to wire from .88 mm. to 2 mm. and even to 2½ mm. It is a universal tool, you can make it very much faster by altering the angle of the nozzle. As regards cost basis, these pistols are sold at between £90 and £100 the first one, but that is not the cost of the pistol itself, it is the cost of the pistol and having your men trained and a certain amount of service after you have started for the solution of your problems. The cost of the process of the coating varies considerably, of course, with the metal which we have to use. To give you some idea, the actual cost of spraying zinc is about 2d. per sq. ft. covered normal thickness, but spraying Nichrome to a thickness of 15 thou. may cost you as much as 30s. per sq. ft. It is

of course, impossible here to give you all the prices between these.

To a question as to subsequent heating spray coating could be subjected to and as regards expansion between two metals supposing they were subjected to 500° to 600°C. after they were sprayed, MR. BALLARD replied: To 600°C. or thereabout sprayed metals are normal, in other words, consistent with the steel underneath it. You have to make allowance for that when spraying very large vessels. If you were spraying a very large vessel bigger than this room with aluminium you sometimes have to make arrangements for a fillet of another metal. Above 600°C. the whole thing changes, because metal spray coating is decidedly porous and above 600°C. these pores fill up so that you get contraction instead of expansion, therefore you have got to be very careful when you treat these things after metal spraying. It is quite possible to do it but you have to take that into consideration. In hardening, for instance, you must remember there is always this contraction at and above 600°C.

MR. SPENCER remarked: You have told us the main uses for metal spraying. Can it be used for plating purposes and is it a commercial proposition when plating?

MR. BALLARD: I take it you mean would you spray when nickel plating? Absolutely, no. With electro deposition you can start with a polished surface, put on a very thin coat, then you can polish slightly. Metal spray coatings are made on a rough surface, therefore you have to put on up to 15 thou. if you get a high finish. It is a case quite out of the ordinary. Only in very rare cases does metal spraying ever come into competition with plating. The only metal sprayers use which electro platers cannot use is aluminium and the only metal metal sprayers cannot use is chromium. We could use that if somebody would make us a pure chromium wire.

MR. BROOMHEAD: Having listened to a lecturer to-night who has been so honest about the possibilities of metal spraying, some people who came here with a knowledge of crystallisation compared with metal spraying, would find him rather disappointing, but we are pleased that he was so frank about what metallisation can do, and that it was only in its infancy. There are one or two questions I would like to ask. For instance, when mild steel spraying, it must be brought up to a heat of 1300°C. The operator shoots that out of a gun and it must undoubtedly be in liquid state and yet is quite cool. I think the lecturer said it was one of the things which mystified him. It is obvious it can be done, because we have samples. Again, when metallising a crankshaft and putting on a deposit of about 15 thou., the particles shot on to the shaft are tubular in shape. If you pile a lot of these up you get, looking end-view, a surface which is nothing but tubes. Therefore, during

your machining processes, no matter whether turning or grinding, you must and I am quite confident in saying that you do create a surface which is all full of little holes.

MR. BALLARD : I have lectured to all sorts of people before, but this is my first lecture to production engineers. Therefore, if I have not stressed those points which you wish to be stressed, I must ask your forgiveness, because as a chemist or metallurgist I perhaps did not stress things I must make clear. Metal spraying is not experimental. You cannot call a thing experimental when the turnover is far more in this country than the nickel plating process ever thought of. The turnover in tonnage of metal deposit by metal spraying is far more than the tonnage of nickel plating. Metal spraying is a technical process, and it is a very pretty process. If you see it you say, " Well, I have never seen anything like that before." The people who started these processes were charmed by their prettiness and they obtained financial support because the things were pretty, and the result is that they have not investigated the matter thoroughly. In the early days all sorts of claims were made whether it could be done or not, but I am in a position to-day to say that over recent years we do not undertake a job unless we know that it can be done satisfactorily. Every job that has not been done before is experimentally tested in the laboratory before it is undertaken. If I told you what had been done, you would be surprised. We have not only metal sprayed metals, but wounds. That is medical science, which is experimental, but what I have told you to-night is absolutely commercial. Take that sample crankshaft. You might say : " I should not like to have that crankshaft in my car "—but that crankshaft would not have been on show if I had not satisfied myself that it was satisfactory. Hundreds of these have been done and some have been in use over eighteen months at least. I could tell you of a tramway casting that has worn $\frac{3}{8}$ in. and the bearing of the inside face has been built up with $\frac{3}{8}$ in. of steel, and after two years it has been in perfect condition, while the opposite one has given out. Answering Mr. Broomhead, there is no mystery about it being cold, 15 cub. ft. of air per minute passes through the pistol, $7\frac{1}{2}$ cub. ft. of air per minute passes through the nozzle. Heating 30 cub. ft. of gas per hour, dissipated by the amount of $7\frac{1}{2}$ cub. ft. of air per minute is very small. The particles of metal passing through, 7 to 12 lb. per hour are very, very small and however hot a particle of metal may be it has a very considerable envelope of air around it which is comparatively cool. The little saucer shape particle you saw was a flattened ring, not a tube and if you build these flattened rings together in all sorts of shapes you will find that you can put them together without very many hollows.

MR. WRIGHT : In putting a thick coating on with the metal spray

process, does it with all metals give sufficient roughness to keep spraying up to say ¼ in. without re-roughening it ?

MR. BALLARD : You put on rings, which is really roughness, then you have actually got little hollows which are the same in size as the next little rows of hollows. You never get a smooth surface, you always get some roughness. It is very difficult to say why it does not smooth out, but it does not.

A MEMBER remarked that regarding cold saucers sticking together the metal gets a shock to sudden cold and he could not understand two cold saucers sticking together.

MR. BALLARD : No, they are not cold saucers but the little expanding rings which flatten are saucer shape. The particle of metal is hot, the surrounding is cold. If you can imagine any one dropping a red hot rivet on to your hand and at the same time as it hits your hand they could put enough dry ice to take all heat out of the rivet. The rivet may strike your hand hot, but it would be immediately frozen by the amount of dry ice round it. The impact is terrific and very very fast, one following another and interlocking. Why metal spray coating does stick is not yet fully understood. After a good deal of research in various countries we must say there is no actual theory which fulfills every point, therefore we must say that we do not know, but we can only say that it is so.

MR. CORKINDALE : What is the recommended air pressure for sand blasting articles and what grade grit, and what would be the effect of the use of condensed compressed air ?

MR. BALLARD : The recommended air pressure is 28.534 lb. The reason is an engineering reason and not metal spraying reason. If you take a curve of the power you have available to compress your air, as pressure increases you get the actual cross. If you take the abrasive effect of sand blasting as pressure goes up the curve goes down in the opposite direction. Where these two cross it must be the actual right pressure at which to sand blast. We vary our pressure to fit in with the economic pressure, and the abrasive used is 30° angular grit and 20° mesh sand and you can get very much the same effect by using very much finer abrasive. We always use in round figures roughly 30 lb. per sq. in. except on porcelain when it falls to 10 lb., because you may break porcelain at a higher figure. The effect of condensing is bad definitely both on sand blasting and on metal spraying, but it is not so necessary to get condensity as it is for paint spraying. In enamelling it is essential that the air must be perfectly dry. While advisable with metal spraying it is not at all necessary. We suggest air from the compressor receiver which is always hot should be taken to a receiver which is outside, so that it falls a little below shop tempera ture,

where you are going to use your sand blasting or metal spraying tool.

A MEMBER : You mentioned earlier that the fescolizing process had certain advantages over metal spraying in building up crankshafts. Does the same condition apply where you are building up tiers for fitting ball bearings, where you have interference fitting on the inner ring of the built up surface and what would be the effect of removing such ring with interference fitting if it was intended to replace a bearing ? One other point, with regard to the training of operators, is there any means of training operators who would not be stationed in this country ?

MR. BALLARD : I did not say fescolizing was any better for building up crankshafts, I should say metal spraying would do crankshafts better. Crankshafts are not subject to shock but are subject to wear. I should say the Fescol process was better if I had a roll to do which I wanted for rolling brass—I should fescolize that. If I had the inside of a 4 in. bore to build up to any thickness I think I should fescolize that, but if I wanted a hard surface on a shaft I should metal spray. With regard to ball bearings, personally I think fescolizing or spraying of steel is absolutely useless in those cases, because you could do it very much cheaper, you could put on a thin coat of zinc by the metal process and it will last a long time. There are thousands of cars which have ball races done in that way and it works perfectly. I know of several big machines which are done in the same way.

Asked if this could be done if you have heavy loads with definite creepage MR. BALLARD replied that if you have creepage or heavy pull you could just fescolize or metal spray, and as regards cost, metal spraying would be cheaper. Where metal spraying can be used it perhaps takes two hours, whereas if you build up with nickel it will take three weeks.

MR. BROOMHEAD : If he wanted to increase or decrease a bearing housing for ball races, then he could spray the inside of the metal housing to about 1½ thou. concentric with existing bearing.

MR. BALLARD : Yes, it is quite right, you would use a rotary nozzle, you could not help being concentric and in this case it is not necessary to have smooth finish, therefore it could be left in the sprayed condition, that has been done quite often. With your nozzle turning at the same time you are bound to get it concentric. As regards the training of operators, there is no country in the world where you could not get it done now, in the British Colonies through their own organizations, in France through the French Official Station in Paris, in Germany, Japan, South America, and practically any country in the world. There are now depots everywhere.

MR. CLARKE : Whereas I can appreciate that spraying pylons

will make them perfectly weatherproof, take the case of something subject to internal pressure. You spray it, then you get a pressure. Is there any likelihood of that corrosive liquid getting through holes in the metallization and corrosion taking place between the deposit and the original mechanism, in other words, similar to rust creeping under a plate ?

MR. BALLARD : While metallizing is not used for anti-corrosive work, it is a process mostly used for building up worn parts, and electric plating is limited to the metal which it uses. Now, metal spraying is not. You take the condition of the surface, you know which metals you want to use and you choose a metal accordingly. You might find it advisable to use two coats, which is quite possible. That is done quite often. With regard to certain pressure vessels, a small porosity in the metal sprayed coating would cause corrosion there, but that should form the subject of a separate lecture. We make use of all the latest facts and information about corrosion of metals. All metals corrode and some take on a film, those that take on films are usually called anti-corrosive. You can get over those difficulties if you know how the vessel is going to be used, you can spray it and form a synthetic film. Vessels used in the sugar industry are sprayed and treated in that method. Glucose has a peculiar method with zinc, but I am afraid I would have to give another lecture on that subject.

A vote of thanks to Mr. Ballard concluded the proceedings.

# LUTON, BEDFORD AND DISTRICT SECTION ANNUAL DINNER.

MR. W. M. PUDGE, Section President, was in the chair at the Annual Dinner of the Luton, Bedford and District Section, held at the George Hotel, Luton, on Tuesday, April 6, 1937, when a company of close on two hundred members and visitors was present.

MR. N. F. STOCKBRIDGE, who proposed the toast of "The Institution," said: It would be remiss of me if I failed to open my remarks without a word of thanks to you for including me among your guests this evening, and—more important still—for the opportunity of saying a few words to you. To-night, for the first time in several years, you meet under circumstances considerably altered. The atmosphere has changed; things are better. The public have more money in their pockets to spend and they can buy with it more than ever before. Now how has this betterment been achieved?

Much as we may agree or disagree with the politics or political faith of the present Government—regardless of whether our leanings be towards free trade or protection—we must all admit that the stability of the British Government has contributed something to the causes underlying the general trade improvement that has taken place since the financial crisis of 1931. Also there may be some merit in the widely-held idea that under the economics of trade cycles an era of prosperity inevitably follows a period of depression. The courage of British industry in its relentless task of exploring every avenue of trade development and expansion both at home and abroad has also undoubtedly assisted the country back on to its feet. And recently, the Government's newly-announced programme of re-armament has given a filip to industrial activity which has brought even the heavy industries of this country back into the impetus of trade improvement.

But to my mind one outstanding cause of to-day's trade revival lies in the ever-persevering and painstaking manner in which our production engineers have done their work during the last few years. In fact, were it not for the production engineer with his ever-recurring improvements in methods, processes and manufacturing equipment, and with his oft-repeated economy in fabricating labour, it is inevitable that the revival in industry and trade would have been seriously delayed—if indeed it had ever arrived at all.

As a matter of interest, this afternoon I called on the Cost Department of the firm over whose activities I have the honour of presiding for some comparative cost figures of some of our instruments and accessory products—figures of to-day and in comparison those of four or five years ago. I am not going to reveal these figures to you because I notice that some of my customer friends are among your guests to-night—and whatever you do, never reveal your costs to your customers. But I can tell you that in three sample cases of representative products, taking our costs in 1931 as 100%, the reductions that we can record since that time are represented by the astonishing figures of 41%, 37% and 31%. It should be noted that these costs are exclusive of variation in the cost of materials—they thus represent the economy secured in fabricating labour, and as such represent the achievement of the production engineer. This achievement is all the more remarkable inasmuch as it is accompanied by greater weekly earnings for each worker than he ever enjoyed in the past.

Now I know from other sources with which I come into contact that these results are by no means exceptional. When I see the value purchasable in to-day's motor-car as compared with five years ago; when I compare the cost of the wireless in my house and the reception I get with it with that ruling in, say, 1931; when I look down the list of domestic products that five years ago could only by their prices be regarded as luxuries for the rich, but which to-day by the reductions in price are becoming to be increasingly regarded as household necessities for all, when I realise all this, I appreciate the debt that is owed to the production engineer of this country.

Another aspect of the work of the production engineer on which I should like to express my admiration lies in the part he plays in the happy labour relations that exist—for the moment, at any rate—in this country. In contrast with the troubled state of the relations between employers and employed, for example, in the United States or in France, we are singularly fortunate. Now, the production engineer is oft-times a major influence in determining the impression that the worker forms of the character, fairmindedness and straight-dealing of his employer. The presentation and solution of production problems are often fraught with grave risk and dissatisfaction on the part of the worker—and it is in many cases only the production engineer with his detailed knowledge of the factors involved who preserves a fair and just equilibrium. In this role he carries heavy responsibilities, and I feel it will be universally admitted that, during the last few years, well has he discharged those responsibilities.

And now, having paid my tribute to the steadfastness, the patience, the tenacity and the perseverance of the body of men

who form the membership of your Institution, may I, in the friendliest manner possible, offer you some comments on certain aspects of your activities. There is to my mind growing up in industry to-day a tendency to overstress the segregation of the functions performed by the designs engineer, the production engineer, the inspection engineer and the sales engineer, and the accounts department. If we examine for one moment the history of industry, particularly of this country, we can readily discern that this segregation is a reaction from the days of the old, what we might describe to-day as the small owner-driven business. Then the boss performed all these functions himself—he told his workpeople what to make, how to make it, he looked it over when it was made, he went out and sold it and then he collected and banked the money.

Now, the establishment and expansion of industries into larger units and groups of units has perforce encouraged—nay, indeed, demanded, and rightly so—a specialisation that has resulted in a segregation of functions that places our engineers into classifications descriptive of those functions. But this tendency has its danger—let me explain particularly with regard to the production engineer. I feel that in your case—maybe I am wrong, I hope so—you are increasingly adopting the attitude that the design of a product is not your concern—your job is to *make* it. Naturally, this is leading the designs engineer to his counterpart attitude that design is his function—he is jealous of it, and concerns himself little if at all with the facility with which it can be manufactured. He almost resents being told that if it were designed differently his product would be easier to manufacture. In fact, haven't you met in some establishments to-day a false sense of pride on the part of both designs and production engineers that they wouldn't dream of trespassing on to each other's domains? Now, to my mind, the development to the extent to which it is taking place is leading to an enormous waste of effort—and unfortunately for this country it is a tendency which seems to have been successfully avoided by our chief manufacturing competitors in the United States.

When we examine many of the manufactured mass-produced products that reach us from America—examine them with a critical eye as to their method of manufacture—how often are we astonished as to the way in which the design of the parts and assembly of the parts have been made with a view to the most economical manufacture—and this without any sacrifice in the products' operating functions.

We in industry in this country have much to learn from our American cousins as to the way their designs and production engineers dovetail their activities. You on your part may feel that my remarks on design were better addressed to a gathering of

designs engineers rather than to a meeting of the I.P.E.—but, gentlemen, this is a question of engineering co-operation—it is up to you so to imbue your respective organisations with the advantages to be gained, that not only your branch but the whole of the team, designs engineers, material purchase departments and all the others, become conscious of the considerable economies that are attainable along the line of so designing a product as to realise its utmost facility for manufacture. Your responsibility—your individual responsibility—towards this aspect of your duties is heavy.

If I were so bold as to offer any advice to H.M. Government in connection with their colossal armaments programme, it would be that they should take advantage of the services of a group of the leading men from your Institution and have them co-operate in the design of the thousand-and-one guns, shells, aero-engines and aeroplanes that go to make up their programme, with a view to facilitating the manufacture of these things. I am confident that without affecting in any appreciable degree the functioning of these various products, the savings to the taxpayers of this country would be enormous. With the field of economy in manufacture that I am certain lies before you and your Institution along the lines I have indicated, you have a real job of work—and I can tell you, so sincerely do I feel in the advice I offer, that I envy you your opportunity—don't miss it. And on this note and leaving you with these thoughts, I ask you to join with me in drinking the health of "The Institution."

Mr. J. H. Bingham, Chairman of Council, responding, said they were all proud of the wonderful progress made by the Institution and the important and responsible position in which Mr. Stockbridge, in his speech, had placed them. I can assure him on behalf of the Institution that the responsibilities which he says are ours will not be shirked. We are not a very old Institution and we have no long heritage, but we are very active. The progress of the Institution has been due in no small measure to the work of the sections. We are proud of the good name of the Institution and those at the top are appreciative of the sections and of the good work which has been done by them. We are here to serve the industrial community in the best possible way we can, and we shall be happy to co-operate with the Government on the lines suggested by Mr. Stockbridge.

It might be the case that there is too great a segregation of function between the various kinds of engineers, but so far as the production engineer is concerned the trend is very definitely towards an expansion of his functions and responsibilities.

Mr. Rupert Allen, proposing the toast of "The Visitors," said: The very able address which has fallen from the lips of Mr.

Stockbridge emphasises very forcibly the great part the Institution of Production Engineers is taking in the general welfare of the community. Whilst not wishing to discount in any way the activities of the Production Engineer, we have none the less to recognise facts. This age we live in is a cheap age and one of tawdry imitation brought about largely by mass-production, and the question we must ask ourselves is what monument this generation will leave to posterity? Even the Queen Mary—almost the finest example of man's skill and patience—must be a scrap-heap in little more than a generation, and yet one needs to travel little to see to-day the achievement those great artists, the Greeks, executed nearly three thousand years ago.

Are we, therefore, not stressing too much the value of the machine and too little that of the human beings behind it? Is not the result of our outlook not tending to drive the skilled man into more lucrative occupations, only to find him not available when he is most wanted? It cannot be denied that skilled men are leaving the land for brick works and skilled men from industry are seeking their fortunes with municipalities, the police force or even in fried fish shops. Where they stick to industry, is not there a tendency for skilled men to man the machine in a semi-skilled capacity rather than remain in the trade which they had been taught? Lastly, is sufficient encouragement given to the rising generation? Does not the young man tend to prefer the higher wage of the non-apprentice with its pot-luck of the future, to the lower wage of the apprentice and the skilled trade of the time to come?

We in Bedfordshire at any rate have seen to it that the non-apprentice has no advantage over the one who is willing to be taught a trade so far as the wage is concerned. It seems to me, therefore, that it is the duty of the Production Engineer, whilst still striving to get the best from the machine, to always keep in mind and surround himself with an ample supply of skilled craftsmen to back the machine. Without such backing industry would reach a most dangerous position. The views I have expressed are probably contentious and disagreeable, but as Mr. Bartlett, the responder to the toast, is in a strong position to put forward the other side of the case, I make no apology for the observations.

Mr. C. J. Bartlett, replying, said that he did not see eye-to-eye with Mr. Allen, but there was plenty of room for both points of view. We must be very careful when looking at a broad problem like this to see that we do not get the wrong perspective.

During the last twenty or thirty years we have transformed this England of ours from a community in which only a few enjoyed very great skill and a certain standard of education.

Now the standard of education has risen and has brought a

responsibility for someone in industry to provide the people with a better standard of living.

In my submission mass-production—to use a very bad term for what I mean—has brought enjoyment into many lives. Under the old standards these things would have been a closed book to many of us. Personally I am a disciple of bringing what progress we can to the world. Many people assume that because there is a great employment of semi-skilled labour it means that there is less employment of skilled labour. That is a great delusion. There is more skilled labour used and required in England to-day, than ever there was. If we change the model of a car we spend at least £100,000 in specialised work, and that money goes to the skilled workmen.

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